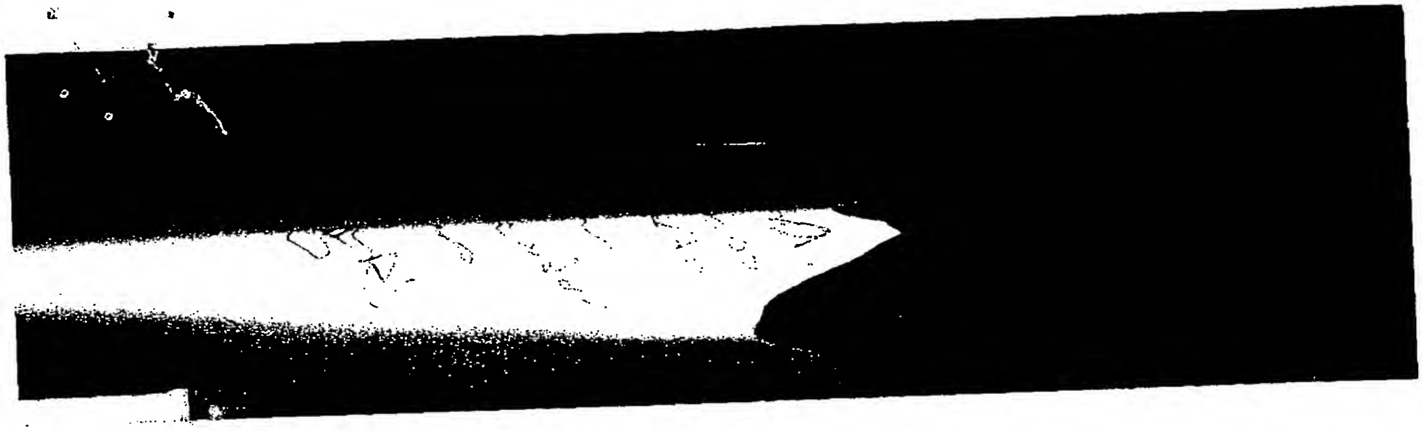

Smart Antennas for Wireless Communications

IS-95 and Third Generation CDMA Applications

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High speed optical data link for Smart Antenna Radio System

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ABSTRACT

In order to simplify site installation and reduce related costs, a high-speed Optical Data Link (ODL) connecting active antennas and Base Station in a new generation Mobile Radio System has been developed. Using the Smart Antennas System in a three-sector site, the number of feeders becomes unmanageable and costly. Thanks to the Multicarrier Software Radio approach, it is possible to place antenna and wide band RF hardware close together, transporting the IF signal in digital format through a high-speed serial data bus. The ODL was built up with Low-Cost Gigabit Rate transmitter/receiver chipset and Gigabit Ethernet 1300nm Laser Transceiver. A 50-meter fibre cable has been used to cope with the standard antenna tower height (a three kilometre fibre length is also possible for distributed antennas in a microcell deployment). Reference signals like A/D and D/A signal clock, local oscillator (LO) and frequency references are delivered to remote parts by optical link as well. The critical aspect related to A/D clock integrity has been successfully solved.

INTRODUCTION

Mobile and Personal communications are playing a more and more important role in the world of economy. It is likely that in the near future, wireless systems will become the prevailing means for the access to communication services. To overcome the spectrum scarcity, smart antenna is a promising technology to increase traffic capacity. At the same time it reduces infrastructure costs and electromagnetic pollution. To verify the benefits and the risk of these new technologies a Smart Antennas test bed employing Multicarrier Software Radio HW architecture has been developed in the R&D Labs of Italtel, according to the GSM recommendations.

The Smart Antenna System has been realised using the Adaptive Antenna technique; this methodology uses spatial filtering algorithms in order to reduce as much as possible the interference signals coming from different azimuthal directions with respect to the useful signal. The Software Radio approach consists in moving the boundary between analogue RF and digital parts of the HW towards the antenna. The purpose of digital radio is to down-converter and to filter (wide band) the desired signal and then to digitize the entire IF bandwidth to be applied to the following digital processing part. The benefit of such receiver is that, in a multicarrier environment, a single unit can serve the entire set of frequencies. In the traditional approach one receiver is needed for each frequency. For these reasons the SW Radio technique reduces costs, size and improves performance.

The Smart Antenna Italtel Test Bed consists of eight WB receivers, eight WB transmitters, a set of digital signal processing units, a planar antenna array with eight elements in azimuth plane and a standard GSM Mobile Station.

To carry out in-field tests, the transceivers are connected to the eight elements of the planar antenna array, each antenna element can be separately phase-amplitude weighted, so sixteen low loss coaxial cables are required (*fig. 1*).

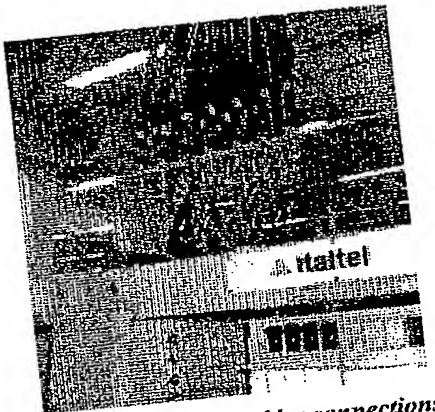

Figure 1: ***Coaxial cables connections***

For direction finding and for combined up-link and down-link beam forming, it is essential to know the actual phase and amplitude of the radiated or received waves of each antenna element. Therefore for an optimum performance of the Adaptive Antenna System, a calibration procedure [1] is essential to know exactly each additional contribution of phase error and amplitude error due to each one of the active or passive elements on signal paths. The calibration consists in two steps. The first one is the off-line calibration of passive components (characterisation off line of each component). The second is the on-line calibration. To do this, a dedicated calibration test set measuring the transfer function of each element signal path in operation must be foreseen. In this way it can account for amplitude and phase errors due to temperature variations, ageing, changing cable connections and so on. So, the coaxial cables constitute a critical aspect for the system calibration. Moreover these coaxial cables are very expensive and cumbersome. For this reason and in order to simplify the complexity of the system it has been preferred to eliminate the coaxial cables placing the analogue transceivers plus A/D and D/A converters close to the antenna and connecting this remote circuitry to the remaining part of the BTS through an optical link. This has become possible, thanks to Low-Cost Gigabit Rate technology, replacing the sixteen coaxial cables by a single high-speed cable with sixteen optical fibre links *(fig.2)*. So this point to point serial connection links active antennas to a digital signal processing part.

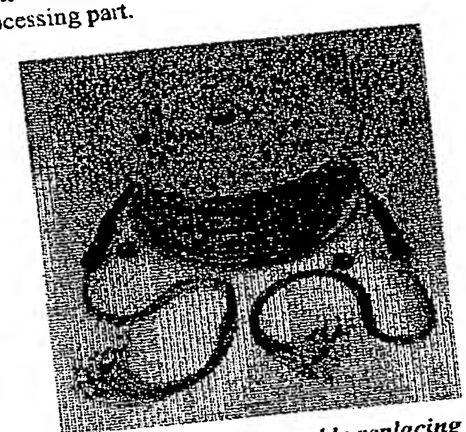

Figure 2: ***Sixteen fibres cable replacing the sixteen coaxial cables***

1. MULTICARRIER SOFTWARE RADIO

Because of the present technological limits in the ADC and DAC design it is for the time being impossible to carry out conversion at RF frequency, particularly in A/D conversion. So in a Multicarrier Software Radio Receiver the IF signal is applied directly to a wide bandwidth ADC; equivalently in a Multicarrier Software Radio Transmitter, at the DAC outputs there is an IF digital signal. The receiver uses direct IF-to-digital techniques by means of under-sampling. The ADC sampling rate is chosen to be at least $2\Delta f$, where Δf is the wide band signal.
The process of sampling the IF frequency at the proper rate causes one of the alias components of Δf to appear in the DC to fs/2 Nyquist bandwidth of the ADC output. This means that ADC converter performs also a frequency conversion from one IF to another IF, then a Digital Down Converter (named DDC) executes the last conversion to Base-Band and the selectivity. DSP techniques can now be used to process the digital base-band signal.

2. HIGH-SPEED OPTICAL DATA LINK FOR SMART ANTENNA TEST BED ARCHITECTURE.

A Smart Antenna Test Bed block diagram with remote RF part is shown in *figure 3*.

It consists in three parts, the first one is the digital signal processor part, the second the optical link and the third the radio interface close the antenna.

A remote link interface is realised by a low cost Gigabit Rate Transmit/Receiver chip set with TTL I/Os, a Gigabit Ethernet 1300nm Laser Transceiver and a 50 meter optical fibre cable. The transmitter accepts 16 or 20 bit wide parallel data (frame) and upon electrical to optic conversion it transmits serial data over a high-speed serial line. The serial data rate of the Tx/Rx link is selectable in four ranges, and extends from 120 Mbits/s up to 1.25 Gbits/s. To achieve Gigabit Data Rates, Laser-Based Technology must be used.

The Gigabit Ethernet IEEE802.3z committee has defined two physical layer specifications for fibre, the first one operating at a long wavelength, 1000BASE-LX, and the second operating at a short wavelength 1000BASE-SX. In the system described the Optical Link typical length is less than 550 meters so 1000BASE-LX in conjunction with 62.5/125 multimode fibre optics has been used.

The transmitter perform the following functions:

- parallel word input,
- high speed clock multiplication,
- frame encoding,
- parallel to serial multiplexing,
- electrical to optical signal conversion.

The Receiver performs the functions of:

- clock recovery,
- data recovery,
- demultiplexing,
- frame decoding,
- frame synchronisation,
- frame error detection,
- link state control,
- optical to electrical signal conversion.

This architecture allows to have only one high stability reference signal next to the local Gigabit Rate Transmitter (BTS digital transmitter side) that delivers the synchronisation signal to the entire system. This is done by clock and data recovery circuits of a remote Gigabit Rate Receiver which extracts the synchronisation signal also for the remote Gigabit Rate Transmitter.

This optical link assures good data transfer quality, but the recovered clock is very noisy to be used as ADC encoder input.

3. ANALOG TO DIGITAL CONVERSION IN MULTICARRIER SOFTWARE RADIO

In Multicarrier Software Radio receivers the ADC input center frequency is usually much higher than the maximum sampling rate. In this case it is necessary to use a particular under-sampler ADC that assures no degradation of the dynamic performance (Effective Number Of Bit and SFDR) for a signal frequency higher than fs/2. Moreover it needs to take care of signal clock integrity versus wide band noise, because it causes jitter (SNR decreases) and distortion (SINAD decreases).

It is in the S&H circuit that the noisy clock produces a phase modulation (jitter) on the ADC input signal. This jitter effect on SNR and SINAD performance is even more dramatic in under-sampling applications because of the higher frequencies. In fact the following equation shows the relationship between jitter and signal frequency:

$$SNR(jitter) = \frac{1}{2 \times \pi \times f_{sign} \times \tau}$$

where τ is the sampling clock jitter and f_{sign} is the signal frequency. It is possible to quantify the jitter amount that assures no worsening of ADC SNR. This jitter amount corresponds to an S&H aperture uncertainty such that the sampled signal amplitude variation is lower than one LSB. Precisely:

$$S = A \cdot sin(2 \cdot \pi \cdot t \cdot f_{sign})$$

$$\left|\frac{dS}{dt}\right|_{MAX} = A \cdot 2 \cdot \pi \cdot f_{sign}$$

$$\Delta t_{MAX} \le \frac{1}{A \cdot 2 \cdot \pi \cdot f_{sign}} \cdot LSB$$

Δt_{MAX} is the maximum peak-to-peak jitter accepted.

$$\Delta f_{MAX} = \frac{1}{T_{CK} - \Delta t_{MAX}} - f_{CK}$$

$\Delta f_{MAX}/2$ is the maximum clock frequency deviation.

In the Smart Antennas Test Bed a 12 bits A/D converter with differential input voltage range of $1\mathrm{Volt}_{pp}$ has been used. The conversion rate and the analog input bandwidth have been chosen equal to 40.083MHz and 10MHz (65÷75MHz). Therefore in the case of f_{sign} = 70.5MHz, the maximum peak-to-peak jitter is ≅1.1ps, and the corresponding maximum clock frequency deviation is ≅ ±880Hz. A Matlab simulation has been realised using a theoretical model of a 12bits flash ADC. It is well known that an ideal 12bits ADC has a SNR value equal to 74 dB. *Figure 4* shows the SNR simulation results corresponding to different values of the peak-to-peak jitter. In the case of jitter lower than or equal to Δt_{MAX} there isn't any SNR degradation with respect to the theoretical value of 74dB. For jitter bigger than Δt_{MAX}, there is a SNR reduction at the ADC output causing a BER worsening.

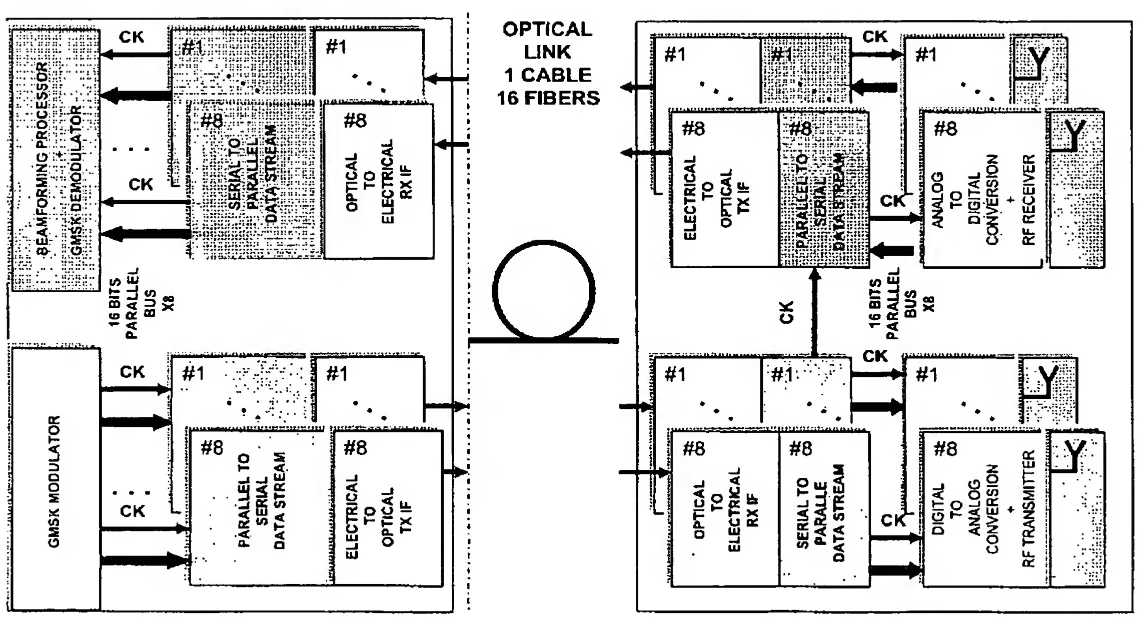

Figure 3: Test Bed Architecture with optical link

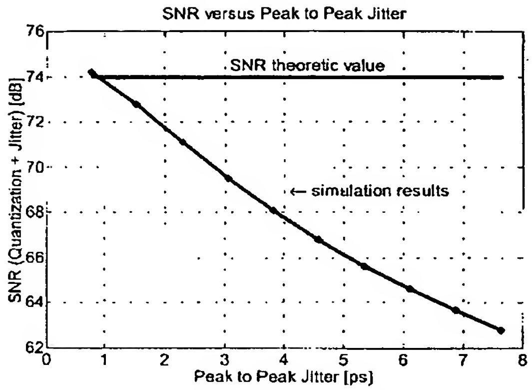

Figure 4 : Simulated SNR versus Peak-to-Peak Jitter

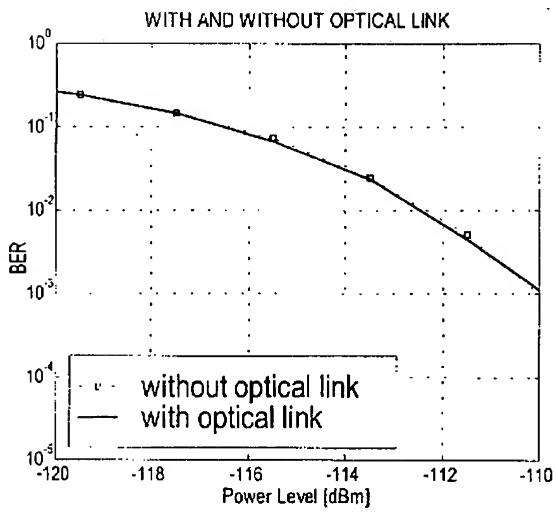

Figure 5 : System BER with and without optical link

To avoid this limitation of performance a suitable filtering with a Δf_{max} filter bandwidth on the encoder signal was employed.
Figure 5 shows comparative BER measurements with and without optical link. No appreciable degradation of the system BER can be noted inserting the optical link

CONCLUSIONS

In this contribution a new system architecture for the Base Stations Transceiver of the mobile radio systems has been suggested. Moreover the problem regarding the critical aspect of signal clock integrity of an ADC encoder input versus wide band noise in Analog to Digital Conversion in a Multicarrier Software Radio System has been analysed and resolved.
Future utilisation of this system is foreseen for the 3rd generation Mobile Radio System (UMTS), using the Smart Antenna concept.

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